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Awesome Foursome? The Compatibility of Driver, Cyclist, Motorcyclist, and Pedestrian Situation Awareness at Intersections

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Abstract. Collisions between distinct road users (e.g. drivers and motorcyclists) make a substantial contribution to the road trauma burden. Although evidence suggests distinct road users interpret the same road situations differently, it is not clear how road users' situation awareness differs, nor is it clear which differences might lead to conflicts. This article presents the findings from an on-road study which examined driver, cyclist, motorcyclist and pedestrian situation awareness at intersections. The findings suggest that situation awareness at intersection is markedly different across the four road user groups studied, and that some of these differences may create conflicts between the different road users. The findings also suggest that the causes of the differences identified relate to road design and road user experience. In closing, the key role of road design and training in supporting safe interactions between distinct road users is discussed.

1 Introduction

Road transport-related trauma continues to be one of the leading causes of death and disability across the world (World Health Organization, 2009). Although significant reductions in death and injury have been made over the last four decades in most motorized countries (Elvik, 2010) a number of complex intractable issues remain. One of these is collisions between different types of road user (e.g. drivers and motorcyclists, drivers and cyclists). For example, an analysis of UK motorcyclist crashes found that their most common cause was other vehicles entering motorcyclists' path when exiting side roads (Clarke et al, 2007). Similarly, the road safety literature suggests that a high proportion of cyclist crashes involve drivers' failing to detect cyclists and colliding with them (Wood et al, 2009). Elvik (2010) identifies incompatibilities between different road user groups as one of five key road safety issues.

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Despite forming a substantial component of the road trauma burden, the causes of collisions between distinct road users remain ambiguous. Moreover, it is not clear what countermeasures are the most appropriate. Recent evidence suggests that the ubiquitous concept of situation awareness has a key role to play in understanding and preventing collisions between different road users. Specifically, studies of road user situation awareness underpinned by Niesser's (1976) seminal perceptual cycle model suggest that differences in road user schema and behavior, driven by experience, transport mode, and road design, may lie at the root of these conflicts (e.g. Salmon et al, 2013; Walker et al, 2011). Low sample sizes have however thus far limited the generalizability of results, and researchers acknowledge the need for further confirmatory research (Salmon et al, 2013; Walker et al, 2011). This paper presents the findings from a large scale on-road investigation of driver, cyclist, motorcyclist and pedestrian situation awareness at intersections. The study involved assessing situation awareness across seventy eight participants whilst they negotiated an urban study route incorporating 3 major intersections requiring a right hand turn. The aim of the study was to identify the key differences in situation awareness between road users, to identify the causes of these differences, and to identify potential conflicts that arise when road users understand the same road situations differently.

2 Assessing Situation Awareness on the Road

Following Salmon et al (2013) and Walker et al (2011), the present study used a network analysis-based approach to describe and assess road user situation awareness. The approach involves constructing situation awareness networks using data derived from the Verbal Protocol Analysis (VPA) method, which involves participants 'thinking aloud' as they perform tasks. Based on content analysis of the VPA transcripts, the situation awareness networks depict the information or concepts underlying situation awareness and the relationships between the different concepts. For example, the concept 'Traffic light' may be related to the concept 'Green' since the traffic light 'is' green. Similarly, the concept 'car' may be related to concepts such as 'speed' (as in car 'has' speed), 'brakes' (as in car 'has' brakes), 'moving' (as in car 'is' moving) and 'driver' (as in car 'has' driver). Mathematical analysis is then used to interrogate the content and structure of the networks. This enables comparison of situation awareness across different actors and scenarios (e.g. Walker et al, 2011).

3 On-Road Study

Situation awareness networks were used to describe road user situation awareness when turning right at three major signalized intersections. A range of quantitative and qualitative network analysis procedures were then used to analyze the content and structure of the networks. In the present paper, the content of the networks is examined as a way of determining what each road user groups' situation awareness comprised when they negotiated the three intersections. Based on previous research (e.g. Salmon et al, 2013; Shahar et al, 2010; Walker et al, 2011), the hypothesis was that the different road users (drivers, cyclists, motorcyclists, pedestrians) would interpret the intersection situations differently. Specifically, there would be differences in the concepts underpinning each road user group's situation awareness. Following this, an investigation into the compatibility between road users' situation awareness and the reasons underpinning the key differences in situation awareness was undertaken.

3.1 Methodology

Design. The study was an on-road study using a semi-naturalistic paradigm whereby participants negotiated a pre-defined route incorporating three major intersections requiring a right hand turn. Drivers drove the Monash University On-Road Test Vehicle (ORTeV), whilst motorcyclists and cyclists completed the route using their own motorcycle or bicycle which was instrumented with video and audio recording equipment. Pedestrians negotiated the three intersections on foot whilst wearing video recording glasses. All participants provided concurrent verbal protocols as they negotiated the study route.

Participants. Seventy eight participants (52 male, 26 female) aged 21 - 64 years (mean = 35.81, SD = 13.03) took part in the study. They comprised 20 car drivers, 18 motorcyclists, 20 cyclists, and 20 pedestrians. An overview of the participants in each group, including gender, mean age and experience is presented in Table 1.

Table 1. Participant demographics

Road user group	**Mean age (SD)**	**Gender**	**Hours drove/rode/cycled/walked per week**
Drivers	34.9yrs (12.53)	10 males 10 females	11.5 hours
Cyclists	32.4yrs (10.42)	15 males 5 females	6.85 hours
Motorcyclists	45.5yrs (12.87)	17 males 1 female	7 hours
Pedestrians	30.5yrs (11.86)	10 males 10 females	8.92 hours

Participants were recruited through a weekly on-line university newsletter and were compensated for their time and expenses. Prior to commencing the study ethics approval was formally granted by the Monash Human Ethics Committee.

Materials. A demographic questionnaire was completed using pen and paper. A desktop driving simulator was used to provide verbal protocol training. A 15km urban route, located in the south-eastern suburbs of Melbourne, was used for the on-road study component.

Drivers drove the route in a 2004 Holden Calais sedan equipped to collect various vehicle, driving scene and driver-related data. A Dictaphone was used to record all participants verbal protocols. Motorcyclists rode the route using their own motorcycle. Each motorcycle was fitted with an Oregon Scientific ATC9K portable camera, which, depending on motorcycle model, was fixed either to the handlebars or front headlight assembly. The ATC9K camera records the visual scene, speed and distance travelled (via GPS). A microphone was fitted inside each motorcyclist's motorcycle helmet and attached to the Dictaphone to record their verbal protocols. Cyclists cycled the route using their own bicycle. To record the cycling visual scene and the cyclist verbal protocols, the ATC9K portable camera was fitted to the cyclists' helmets, and cyclists wore Imging HD video cycling glasses. Pedestrians negotiated the intersections on foot whilst wearing Imging HD video sunglasses and a microphone linked to a Dictaphone. All verbal protocols were transcribed using Microsoft Word.

For data analysis, the Leximancer™ content analysis software was used.

Procedure. In order to control for traffic conditions, all trials took place at the same pre-defined times on weekdays (10am or 2pm Monday to Friday). Participants first completed an informed consent form and demographic questionnaire and were then briefed on the research and its aims (expressed as a study of driver behavior). Following this they were given training in providing verbal protocols which included a desktop driving simulator task where they were asked to complete the drive whilst providing a verbal protocol. An experimenter monitored the drive and provided feedback to the participant regarding the quality of their verbal protocol. Participants were then shown the study route and were given time to memorize it. When comfortable with the verbal protocol technique and route, participants were taken to their vehicle and asked to prepare themselves for the test. They were then given a demonstration of the video and audio recording equipment, which was also set to record at this point. Following this, the experimenter instructed the participant to begin the study route. For the drivers, an experimenter was located in the vehicle and provided route directions if necessary. For the motorcyclists and cyclists, an experimenter followed behind (in a car for the motorcyclists, on a bicycle for the cyclists) ready to intervene if the participants strayed off route. Pedestrians were taken by car to the first intersection and instructed to negotiate the intersection and walk to a set point following the intersection. Once the participant reached this point, they were picked up by the experimenter and driven to the next intersection. This process was repeated until all three intersections had been negotiated.

Participants' verbal protocols were transcribed verbatim using Microsoft Word. For data reduction purposes, extracts of each verbal transcript for each intersection were taken from the overall transcripts. The extracts were taken based on the video data and pre-defined points in the road environment (e.g. beginning and end of intersection). The verbal transcripts were then analyzed using the Leximancer content analysis software in order to create situation awareness networks. Leximancer uses text representations of natural language to interrogate verbal transcripts and identify themes, concepts and the relationships between them. The software does this by using algorithms linked to an in-built thesaurus and by focusing on features within the verbal transcripts such as word proximity, quantity and salience. The output is a network showing concepts and the relationships between them according to the transcript.

4 Results

Leximancer was used to construct overall driver, cyclist, motorcyclist and pedestrian situation awareness networks for each intersection. The four networks for each intersection were then mapped onto one another to produce a multi-road user situation awareness network for that intersection. For example, the multi-road user situation awareness network for intersection 1 is presented in Figure 1. Within Figure 1 the nodes and links are shaded to depict each road user group's situation awareness. Figure 1 shows how situation awareness differed across the distinct road user groups whilst negotiating intersection 1, both in terms of the concepts underpinning situation awareness (i.e. nodes in the network), and also in the way in which the concepts were linked together (i.e. links between the nodes in the network). Moreover the network demonstrates that, even when the different road users were using the same concept, they were doing so in conjunction with other different concepts. This pattern is repeated over the other two networks studied (the networks for intersections 2 and 3 are not presented due to space constraints). The multi-road user situation awareness networks therefore confirm that driver, cyclist, motorcyclist, and pedestrian situation awareness was different when negotiating the three intersections studied.

The differences in situation awareness are explored further in Table 2, which presents a summary of concept usage across the four road user groups for each intersection. Table 2 shows that, at intersection 1, only 19% of all concepts from the multi-road user network were used by all road user groups. Similarly, only 20.9% and 14.6% of concepts were found in all four road user groups situation awareness networks at intersection 2 and 3 respectively. Table 2 also shows that, at intersection 1, around 5% of all concepts were unique to drivers, around 10% were unique to cyclists, around 10% were unique to motorcyclists, and almost 20% were unique to pedestrians. A similar pattern is also found at intersections 2 and 3.

Table 2 also shows how some concepts were common across different combinations of the four road user groups. For example, almost 10% of concepts at the three intersections were found in driver, cyclist, and motorcyclist situation awareness networks, but not in the pedestrian networks. Interestingly, at intersection 3 over 10% of the concepts were found in both cyclist and pedestrian situation awareness networks. This is likely due to the complexity and high risk nature of intersection 3, which meant that many cyclists exploited the pedestrian crossings when negotiating the intersection.

Figure 2 shows the 'common' concepts (i.e. those found in all road user groups situation awareness networks) along with the concepts unique to each road user group at each intersection. Figure 2 shows that the concepts common across all four road user groups at the three intersections were mainly related to the cars, traffic, the road, the lights and their status (e.g. green), the intersection, and the act of turning. This reflects a high focus of all road users on cars, the traffic lights, and the intersection environment itself.

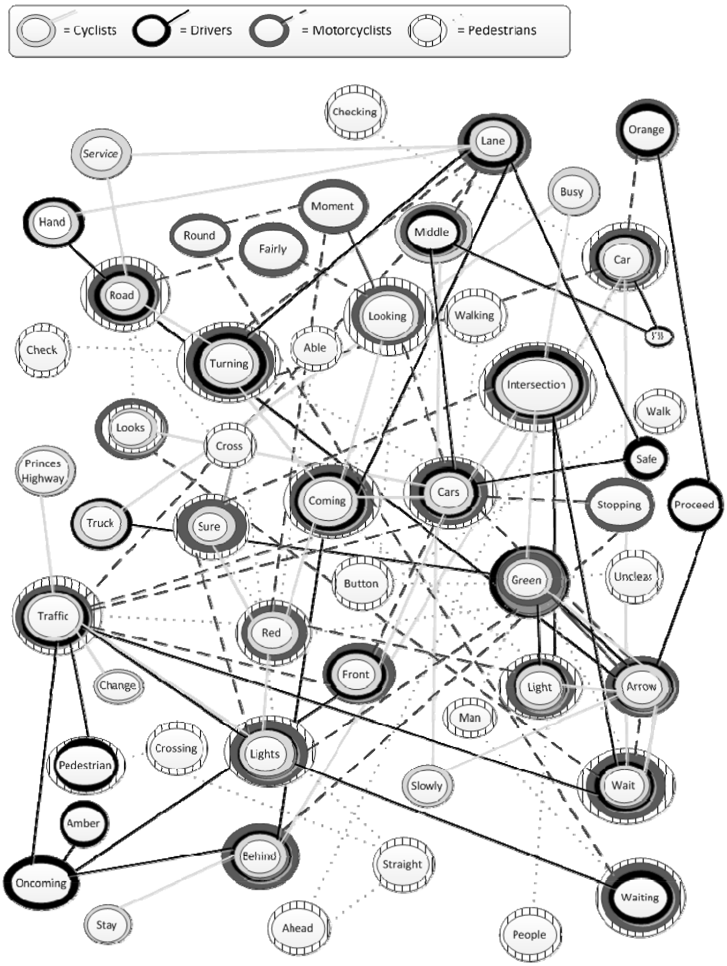

Fig. 1. Intersection 1 situation awareness network showing driver, cyclist, motorcyclist and pedestrian situation awareness networks mapped onto each other

Important differences in concept usage are shown in Figure 2. At intersections 1 and 2, the cyclist networks include the concepts ‘service’, ‘stay’ and ‘route’, all of which reflect a key decision that they face regarding whether or not to use the service lane on approach to the intersection and then cross via the footpath, or to stay on the road and go through the intersection in the normal traffic flow. Moreover, prior to the intersection the cyclists also decide whether they will leave the road and get back into the service lane once they have passed through the intersection. At intersection 3, the cyclists' network included the 'hook' concept, which refers to their decision regarding whether or not to use a hook turn in order to turn right at the intersection. Again this reflects a key decision whereby cyclists try to work out whether it is safe enough to pass through the intersection on the road within the flow of traffic or whether they need to perform a hook turn to avoid conflict with other traffic also turning right.

Table 2. Concept usage across the road user groups

	Int 1	**Int 2**	**Int 3**
Drivers			
Number of concepts	19	22	23
Unique concepts	2 **(4.9%)**	1 **(2.3%)**	6 **(13%)**
Cyclists			
Number of concepts	25	23	23
Unique concepts	4 **(9.8%)**	6 **(14%)**	2 **(4.2%)**
Motorcyclists			
Number of concepts	23	25	24
Unique concepts	4 **(9.8%)**	5 **(11.6%)**	7 **(14.6%)**
Pedestrians			
Number of concepts	22	23	26
Unique concepts	8 **(19%)**	5 **(11.6%)**	9 **(18.8%)**
Common concepts			
Concepts common across all road user groups	8 **(19%)**	9 **(20.9%)**	7 **(14.6%)**
Concepts used by drivers, cyclists, and motorcyclists only	4 **(9.8%)**	3 **(7%)**	4 **(8.3%)**
Concepts used by drivers, cyclists, and peds only	1 **(2.4%)**	2 **(4.7%)**	2 **(4.2%)**
Concepts used by drivers, motorcyclists, and peds only	-	1 **(2.3%)**	1 **(2.1%)**
Concepts used by cyclists, motorcyclists, and peds only	4 **(9.8%)**	1 **(2.3%)**	2 **(4.2%)**
Concepts used by drivers and cyclists only	2 **(4.9%)**	-	1 **(2.1%)**
Concepts used by drivers and motorcyclists only	1 **(2.4%)**	4 **(9.3%)**	1 **(2.1%)**
Concepts used by motorcyclists and cyclists only	2 **(4.9%)**	1 **(2.3%)**	1 **(2.1%)**
Concepts used by drivers and peds only	1 **(2.4%)**	2 **(4.7%)**	-
Concepts used by cyclists and peds only	-	1 **(2.3%)**	5 **(10.4%)**
Concepts used by motorcyclists and peds only	-	2 **(4.7%)**	-

For the motorcyclists, the unique concepts relate primarily to the selection of the left or right hand lane to negotiate the intersection (e.g. 'hand', 'left hand', 'merging'), the motorcycle itself (e.g. 'bike', 'gear') and the 'line' that they should take through the intersection. The 'stopping' concept refers to motorcyclist's own braking behavior, but also to them checking that other traffic approaching from behind are stopping when the traffic lights are on red.

For the pedestrians, the unique concepts were primarily related to the physical acts of walking (e.g. 'walk/walking) and crossing the road (e.g. 'cross/crossing') and also the crossing infrastructure (e.g. 'button', green 'man'). Interestingly, only the pedestrian networks included the concepts 'check/checking' and 'look/looking', which indicate that the other road users placed less emphasis on checking other traffic and the road environment when negotiating the intersections.

Intersection 1				
Common across all road user groups	**Unique to drivers**	**Unique to cyclists**	**Unique to motorcyclists**	**Unique to pedestrians**
Car(s), Road, Light(s), Green, Intersection, Traffic, Wait/ Waiting, Coming	Safe, I'll	Service, Road name, Slowly, Stay	Stopping, Fairly, Moment, Round	Walk/ Walking, Check/ Checking, Button, Ahead, Man, Cross/ Crossing, Able, Straight

Intersection 2				
Common across all road user groups	**Unique to drivers**	**Unique to cyclists**	**Unique to motorcyclists**	**Unique to pedestrians**
Car(s), Lane/ Lanes, Light(s), Green, Intersection, Sure, Red, Straight, Turning	Pull	Service, Time, Ready, Stay, Take, Route	Hand, Left Hand, Bike, Gear, Line	Turned, Anyway, Button, Man, Seems

Intersection 3				
Common across all road user groups	**Unique to drivers**	**Unique to cyclists**	**Unique to motorcyclists**	**Unique to pedestrians**
Car(s), Coming, Light(s), Green, Intersection, Red, Turning	Change/ Changing, Right hand, Forward, Making, Notice, Route	Hook, Doing	I'll, Hand, Moving, Gear, Merging, Assume, Stopping	Middle, Walk/ Walking, Able, Check/ Checking, Clear, Flashing, Look/ Looking, Button, Man

Fig. 2. Common and unique concepts across road user groups at each intersection

5 Discussion

The aim of this study was to confirm previous exploratory study findings which indicate that different road users experience the same road situations differently (e.g. Salmon et al, 2013; Walker et al, 2011) and to explore the causes and effects of these differences. The analysis presented demonstrates that driver, cyclist, motorcyclist, and pedestrian situation awareness was different when negotiating the same three intersections. Specifically, different concepts were found in the distinct road users' situation awareness networks, and even when the same concepts were present, the integration with other concepts in the networks was different across the road user groups studied. These findings point to the conclusion that distinct road users experience the same intersections differently to one another. They possess different intersection schema, perform different tasks, interact with the environment differently, and integrate information regarding the intersection situation differently, all of which culminates in a markedly different understanding of the intersection situation.

The next aim was to examine whether these differences are safe or not. Given the nature of the different road users' tasks (e.g. operating a motorcycle versus walking) it is not surprising that their situation awareness differs in some way; however, it is also apparent that some differences may lead to conflicts. Examination of the unique and common concepts (Figure 2) raises some concerns. The unique cyclist concepts 'service', 'stay', 'route' and 'hook' derive from the key decision on approach concerning whether they should negotiate the intersection on the road within the traffic flow, via the pedestrian crossing, or via a hook turn and then also whether they should stay on the road after the intersection or head into the service lane. From a situation awareness perspective, this decision is informed by awareness of the real-time safety risks associated with each path through the intersection and of the ease of taking one option over the others. The result may be that cyclists' attention is taken away from the traffic surrounding them whilst they focus on working out which route through the intersection is the safest and easiest to access. Moreover, once the route through is decided upon, a major maneuver may be required (for example, moving across three lanes of traffic into the service lane, or from the service lane onto the road and into the right hand lane). When this is considered with the fact that the other road users had a high focus on cars, the traffic lights, and the act of turning right, along with the absence of 'check/checking', 'look/looking', and left or right 'hand' side concepts, a major conflict becomes apparent. That is, cyclists are required to focus their attention on situational features other than the traffic and then potentially make a major maneuver in close proximity to the intersection, whereas drivers are not expecting cyclists to make these maneuvers and may not be checking the environment for them.

A similar issue was found with the motorcyclists, who appeared to have a focus on the 'line' to be taken through the intersection, and on the selection of the most appropriate lane in which to negotiate the intersection. Again this represents a key decision point for motorcyclists and also creates the potential for lane change maneuvers in close proximity to the intersection, whereas the driver networks do not contain concepts related to checking and looking for other road users. This represents a potential conflict in that motorcyclists are making maneuvers just prior to the intersection, but drivers may not expect these maneuvers or be on the lookout for motorcyclists.

The evidence suggests, therefore, that the propensity for cyclists and motorcyclists to seek the safest path through the intersection may be raising potential conflicts with drivers. It is apparent that there are two factors creating these potential conflicts: the way in which the intersection is designed, and driving experience. In the case of road design, cyclists and motorcyclists face a key decision in close proximity to the intersection itself, and intersection 'systems' do not support either decision. Moreover, the intersection system does not make other road users (e.g. drivers) aware of the likelihood that cyclists and motorcyclists could potentially make major maneuvers in close proximity to the intersection itself. In the case of road user experience, it appears that drivers are not expecting cyclists and motorcyclists to be maneuvering in and around the intersection, which in turn means they are not looking for them.

One solution is to design intersections that support situation awareness and decision making across all road users and which increase road users' awareness of how other road users behave. For example, it would be useful to ensure that cyclists and motorcyclists decide on the path through the intersection earlier and away from the complex intersection situation. This could be achieved by constraining behavior; for example, taking cyclists and motorcyclists through the intersection via dedicated bicycle and motorcycle lanes. Road signage encouraging drivers to be on the lookout for motorcyclists and cyclists maneuvering across traffic lanes would also be useful. Another solution is the provision of driver training focused on developing an understanding of other road users' behavior. Research has shown that drivers who are also licensed motorcyclists are involved in fewer car-motorcycle collisions than car drivers who do not hold a motorcycle license (Magazzù et al, 2006). The concept of cross mode training (Maguzzù et al, 2006) where different road users receive training in how other road users interpret the road situation and behave in different situations could be useful for developing anticipatory schema of other road users in drivers. The next phase of this research program will explore new intersections design concepts designed to support situationa awareness across all forms of road user.

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